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Clemans A. Powell

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Clemans A. Powell
Langley Research Center
Hampton, Virginia

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SUMMARY

A laboratory study was conducted to investigate the annoyance effects of multiple aircraft noise exposure in which 250 subjects judged the annoyance of half-hour periods of airplane noise simulative of typical indoor home exposures. The variables of the aircraft noise exposure were the A-weighted peak noise level of flyovers (56, 62, 68, 74, and 80 dB(A)), which was constant within each period, and the number of flyovers (1, 3, 5, 9, and 17 per period). Each subject judged 5 of the possible 25 factorial combinations of level and number. Other variables investigated included the experience of the test subjects in making annoyance judgments and their home exposure to airplane noise. The subjects were asked to judge each session as to how annoyed they were in the laboratory and to project how annoyed they would be if they heard the noise in their homes during day, evening, and night periods.

The annoyance judgments increased with both noise level and number of flyovers. The increased annoyance produced by doubling the number of flyovers was found to be the equivalent of a 4- to 6-dB increase in noise level. The sensitivity of the subjects to changes in both noise level and number of flyovers increased with laboratory experience. Although the means of the annoyance judgments made in the laboratory were found to decrease with the subjects' home exposure to aircraft noise, the subjects' sensitivities to changes in both level and number were unaffected by their home exposure. Based on the responses to the home-projection annoyance questions, appropriate time-of-day penalties were found to be 5 dB for evening and 8 to 15 dB for night periods.

INTRODUCTION

The prediction of annoyance due to aircraft noise exposures should consider not only the intensity or level of the aircraft noise events but also the number of such events per time period. Although much research has been conducted on the noisiness characteristics of individual aircraft flyovers, relatively little information has been reported on the influence of different numbers on annoyance. As a consequence, most of the models which have been suggested for predicting annoyance due to multiple aircraft are quite diverse in the manner of accounting for number of flyovers per unit time.

The U.S. Environmental Protection Agency (ref. 1) suggested that an equivalent energy method be used to account for level and number. (A doubling of the number of events equated to a 3-dB increase in level.) The "dB(A) peak concept" proposed in reference 2 suggests that if the total number of operations exceeds 50 per day, annoyance is proportional to the peak level of the noisiest aircraft. An additional proviso is that the noisiest aircraft type must exceed two operations per day. Based on community annoyance surveys and the meager amount of reported laboratory research, neither of these models could be completely supported.

In a reanalysis of several community surveys (ref. 3), the effects of number of aircraft and other noise events were examined for the possibility of a trading relationship between level and number. Although annoyance was found in each survey investigated to increase with increased numbers of flyovers per unit of time, thereby not supporting the "dB(A) peak concept," the trading relationships varied from 0.2 to 7.2 dB per doubling of number of flyovers in the different surveys. There was, however, high correlation between noise level and number of events within each survey. Also, the possibility exists of error in the actual noise exposure of respondents. Consequently, the trading relationships could not in general be shown to be significantly different from the 3 dB per doubling of the energy model.

Laboratory studies such as references 4 to 6 have not provided conclusive evidence of the validity of an energy model. In these studies, subjects made single annoyance or acceptability judgments to extended periods which contained different numbers of flyovers. In reference 4, a trading relationship between number and level could not be reliably established because of the design of the experiment.

The results of reference 5, although generally supportive of an energy-type model, indicated several interesting anomalies. The first anomaly was that the trading relationship was dependent on the rate of flyovers; the relative effect of number was greater at high rates. The second anomaly was that the trading relationship between number and level was dependent on the annoyance judgment experience of the test subjects. No effect of number was found for the subjects' first condition of laboratory noise exposure.

The results of the series of experiments reported in reference 6 also generally supported an energy-type model. However, in the experiments in which the number of noises was a variable, only simulated flyovers were used. These simulated flyover noises were judged significantly less acceptable than actual aircraft flyover noises with equivalent energies.

The primary purpose of the study reported herein was to investigate the effects of number of flyovers per session on annoyance due to airplane noise relative to the effects of the level of the noise. Particular objectives of the conducted study were to

1. Investigate the applicability of the "energy" and "dB(A) peak concept" models as well as several other models for predicting annoyance due to airplane noise exposures

2. Investigate the possible effects of subject experience on laboratory annoyance responses

3. Investigate possible time-of-day effects by asking subjects to project their annoyance to day, evening, and night periods at home

In the study, subjects in a simulated living room environment made annoyance judgments on half-hour sessions of airplane noise consisting of different noise levels and numbers of flyovers. The details of the design and results of the experiment are reported herein.

SYMBOLS

EPNL	effective perceived noise level, dB
F-ratio	ratio of variances
K	constant used in noise number correction factor K log N
L_A	A-weighted peak noise level, dB
L_{dn}	day-night average sound level, dB
L_{eq}	equivalent continuous sound level (energy-averaged), dB
L_{np}	noise pollution level, dB
N	number of airplane noise events
NEF	noise exposure forecast, dB
NNI	noise and number index, dB
r	Pearson product-moment correlation coefficient
R	multiple correlation coefficient
SEL	sound exposure level, dB
TCPNL	tone-corrected perceived noise level, dB
t-value	student t-statistic
β	regression coefficient
σ	standard deviation

Subscripts:

1	noise level
2	number of flyovers

More details of the indices and scales for acoustical measurements can be found in a number of general noise references, including reference 7.

EXPERIMENTAL METHOD

Test Facility

The interior effects room of the Langley Aircraft Noise Reduction Laboratory (fig. 1) was used in the present experiment. This room was designed to

resemble a typical living room and to allow controlled acoustical environments to be presented to subjects. The construction of the test room is typical of modern single-family dwellings.

The loudspeaker systems used to produce the airplane noise stimuli were located outside the test room to provide a realistic simulation of residential airplane noise. Reference 8 presents an additional description of the facility and the results of acoustic measurements which show that airplane noises presented to test subjects in this facility are representative of those measured inside typical dwellings.

Noise Stimuli

The noise stimuli used in the study were five recorded take-off noises of Boeing 727 airplanes. Each of the recordings was made at different slant range distances, so that the level, duration, and spectral content of the flyovers were coupled in a realistic manner. That is, the highest level flyover had the shortest duration and contained the greatest high-frequency energy relative to the other flyovers. The lowest level flyover had the longest duration and contained the least relative high-frequency energy. Time histories of the A-weighted sound pressure level L_A for each of these flyover noises are presented in figure 2. The noise levels of the flyovers as presented to the subjects are given in table I. Outdoor noise levels estimated to produce such indoor noise levels are also given.

A total of 25 noise conditions were used in the experiment. These consisted of the factorial combinations of the five noise levels and five numbers of flyovers (1, 3, 5, 9, or 17) presented during half-hour exposure sessions. A computer-controlled tape recorder system produced the proper flyover stimulus at the correct level and number of times during each session as determined by the preprogrammed experimental design described in the next section.

Experimental Design

The chosen design was based on an incomplete block 5^3 factorial design with repeated measures (ref. 9). Subject groups served as the blocking factor. The three main factors were noise level, number of flyovers, and order of presentation. The order of presentation was considered to be a factor of interest so that the possible effects of judgment experience of the test subjects could be investigated.

The order of presentation of the conditions of level and number of flyovers is presented in table II. The 250 subjects were randomly assigned to groups of 5 subjects. Each person made judgments on five level-number conditions. The presentation order shown in table II is for the first 25 subject groups. Subject groups 26 to 50 received the same conditions as groups 1 to 25, respectively, except in reversed presentation order. The presentation order for each succeeding five-subject group was based on a Greco-Latin square of the level-number conditions. As can be seen in table II, each level-number condition occurred once in each order position for the first 25 subject groups and

similarly for the last 25 subject groups. The design was therefore balanced for order of presentation.

Because of time limitations, it was not possible for each subject group to judge all order-level-number conditions. The design was therefore incomplete. Subject groups served as the blocking factor and consequently were confounded with some other effects (ref. 9). The particular combinations of order, level, and number given to the subject groups were chosen to minimize the loss of information. The confounding scheme selected did not affect the main effects of number, level, and order and only partially affected some interactions. More consideration of this confounding will be given in a later analysis section.

Subjects

The 250 subjects for this experiment were paid volunteers from the general population of the cities of Hampton and Newport News and from York County in Virginia. None had previous experience in any form of psychological judgment tests. Most of the subjects, 185, were female. Their ages ranged from 18 to 66 years (mean, 32.4 years). The ages of the male subjects were between 18 and 64 years (mean, 26.4 years).

Procedures

Upon arrival at the laboratory, each subject was given instructions for the experiments. After the subjects had read the instructions, the test conductor asked if there were any questions and verbally reinforced the use of the numerical category scale used for their annoyance responses. The instructions and scoring sheets are duplicated in appendix A. The subjects were first requested to judge the noise of each session with regard to their feelings of annoyance in the laboratory situation. They were then requested to judge the noise session in terms of how they would feel about the noise if they heard it in their homes. This home-projected annoyance question was divided into three time periods - day, evening, and night.

The subjects were also requested to indicate on the scoring sheets whether or not they were highly annoyed by the noise in the session. This was also divided into laboratory and day, evening, and night home-projection sections. A similar technique was used in references 5 and 10 for the comparison of laboratory-annoyance studies with community-survey results. Although the validity of these techniques for comparison has not been universally established, the results of references 5 and 10 indicate relatively good agreement with community-annoyance surveys such as those reported in reference 11.

After the instruction period, the subjects were escorted to the test facility, randomly assigned seats, and again asked if they had any questions. After each test session, the test conductor returned to the facility and gave the scoring sheets to the subjects for their judgments. A 15-minute rest break was given after the third session. After the fifth session, the subjects were asked one final question, which is also duplicated in appendix A. This concerned their annoyance to the total of all of their noise exposures. This question

was to provide information on the subjects' annoyance for longer periods and on the manner in which the subjects integrate their annoyance to more complicated exposures.

RESULTS AND DISCUSSION

Analysis of Variance for Annoyance Questions

The subjective response data for the laboratory annoyance and three cases of projected home annoyance were analyzed separately by the same analysis of variance technique. The analysis considered the data as a replicated incomplete block 5^3 factorial design with repeated measures and was based on an extension of a 3^3 design presented in reference 9. A summary table of the analysis for the laboratory annoyance question is presented in table B1 of appendix B. Abbreviated results are presented in table III. From this analysis it is clear that both level and number of flyovers were significant ($p \leq 0.01$), whereas no order effect was found. Although the interactions of order and level; order and number; level and number; and order, level, and number were each significant ($p \leq 0.01$), the relative effects of the interactions were small compared with the effects of level and number.

Very similar results were found for the day, evening, and night home-projection questions (tables B2, B3, and B4 in appendix B and tables IV, V, and VI), with a few exceptions. Level and number of flyovers were found to produce the major significant effects. For the evening and night questions, however, the order of presentation was also found to be significant ($p \leq 0.01$). Those effects found to be significant and concerned directly with noise level, number of flyovers, and order are examined in more detail in sections to follow.

As mentioned in a previous section, the design was an incomplete block design and consequently some confounding of effects was present. The blocking factor was subject groups, and some portions of the interaction terms were thereby confounded with between-group effects. The sums of squares attributable to subject differences (between groups and subjects within groups) show an interesting trend across the annoyance questions. The laboratory and day home-projected results are very comparable. The results for the home-projection evening questions indicate an increase in variability over the laboratory and day question. The results for the night questions indicate an even greater variability. There are some increases in the sums of squares attributable to within-subject effects across the questions; however, these are not proportionally as great as the increases in the between-subjects effects. This indicates that, individually, the subjects were generally consistent in describing how they were affected by the noise variables of level and number across the different questions. However, there was more variability between subjects in describing how they thought they would be affected during the different time periods.

Effects of Noise Level and Number of Flyovers

The use of numerical category scaling in psychophysical tests as described in this report frequently results in nonlinearities in response at both the upper and lower end of the fixed scale. These nonlinearities result from the fact that the judgments for stimuli near the ends of the subjective scale are limited by the scale and tend to deviate significantly from a normal distribution. In order to reduce the effect of this type of nonlinearity, the data were processed by using the method of successive intervals described in reference 12. The annoyance data processed by this technique are designated as "normalized" in subsequent sections of this report.

Effects of noise level.- The primary effects of noise level on normalized annoyance judgments are indicated in figure 3. The data were grouped according to the number of flyovers in a session, and regression analyses were performed for each group. Annoyance judgments increased with increases in noise levels in a generally linear manner. Although the analysis of variance of table III indicated a small but significant interaction between noise level and number of flyovers, the regression analyses of the normalized data indicate no significant or consistent slope differences. The interaction indicated as being significant by the analysis of variance could be a result of nonlinearity in the scaling procedure.

Effects of number of flyovers.- The overall effects of number of flyovers are indicated in figure 4. The data are plotted using a logarithmic scale for the number of flyovers per session. There was a generally consistent and linear relationship between annoyance and $\log N$. The greatest deviation from this trend was exhibited at the highest noise level, where above 3 flyovers per session, very little increase in annoyance was found for further increases in the number of flyovers. A similar trend was found in the survey data of reference 13 at all noise levels. A somewhat lessening effect of number of flyovers at high rates was also found in the laboratory study of reference 5. Neither the results of the present study nor those of references 5 and 13 completely support the "dB(A) peak concept" model of reference 2, since increased number of flyovers did produce increased annoyance at flyover rates greater than 50 per day (approximately 1 per half-hour).

Relationship between number and level.- For most cumulative noise indices which specifically or inherently account for the number of noise events, a factor of the form $K \log N$ is added to the noise level, where K is a constant and N is the number of events occuring in a given time period. Various values of K are used in different indices, the values 10 and 15 being most common. To provide a comparison of the effect of number of flyovers in the present study with results of other research and various noise metrics, optimum values of the constant K were calculated. These values were determined by performing multiple linear regression analyses on the normalized annoyance values with noise level and $\log N$ as independent variables. The results of these analyses are given in table VII for several different measures of single-event noise

level. The ratio of the coefficient of the number effect to the coefficient of the noise level provides the optimum value of the constant K. The optimum values of K are somewhat dependent on the noise measure and vary from 14.0 to 19.3. These values are greater than the K value of approximately seven found in the laboratory studies reported in reference 5. They differ less, however, from the value of 15 for a railway noise survey reported in reference 3 and from the value of 24 for the 1961 Heathrow aircraft noise survey (ref. 14).

As indicated by the rather large confidence limits on K in table VII, some uncertainty exists in the determination of the optimum value of the trade-off effect. Although a significant improvement in annoyance prediction ability was accomplished by the inclusion of a log N term in the regression analyses, the multiple regression correlation coefficient is a rather slowly varying function of K near the optimum value. This is indicated in figure 5. Very nearly the same functional relationships were found for L_A, SEL, and EPNL. The relationship for TCPNL was somewhat more slowly varying near the optimum value of K than for the other measures, although the correlation at the optimum value was somewhat greater.

Table VII also gives the optimum correction to noise levels to account for the number of flyovers per session. This factor was equivalent to a 4- to 6-dB increase (decrease) in level per doubling (halving) of the number of flyovers, depending on the noise level metric employed. The effect of number of flyovers was thus somewhat greater than the 3 dB per doubling implied in energy-based metrics such as L_{eq} and L_{dn}.

Predictability of Annoyance

Linear regression analyses were performed on the normalized laboratory annoyance response to compare the prediction ability of several single-event and multiple-event noise metrics. The results of these regressions using values of single-event noise measures as independent variables are presented in table VIII. Included in the table are the correlation coefficients between the normalized annoyance response and the measures TCPNL, L_A, EPNL, and SEL; the intercorrelation between the measures; and calculated t-values for testing the significance of differences in prediction ability between the noise measures. Although the correlation between annoyance and TCPNL was greater than for the other measures, the differences were not significant. The intercorrelations between all the measures were very high (≥ 0.995). Since the same type of aircraft was used for the different noises in the study, the high intercorrelation is not altogether unexpected.

Results of the regression analyses using values of cumulative or multiple-event noise measures as independent variables are presented in table IX. The correlations between the normalized annoyance response and each of these noise measures were greater than for the single-event noise measures. An additional 20 percent or more variance in annoyance response was accounted for by the inclusion of the types of corrections for number of events inherent in these particular cumulative noise measures. Although the intercorrelations between measures were relatively high, significant differences in annoyance prediction

ability were indicated. NNI was significantly better than each of the other three measures and explained approximately 4 percent more variance than L_{eq}. This results from the following two factors. The noise level measure in NNI is TCPNL, which was found in this particular study to be more highly correlated with annoyance than were the other single-event noise measures. The primary factor, however, is the manner in which the number of events is accounted. A 15 log N term was used with NNI rather than the 10 log N term inherent or included in the other measures.

A somewhat surprising finding was that the correlation for L_{eq} was significantly higher than that for NEF. This was surprising because the correlation for SEL was not found to be higher than that for EPNL (table VIII). Also, the energy summation of L_{eq} and the 10 log N term for NEF should be equivalent. The reason for the increased correlation can be found in figure 5. The optimum value for K was somewhat closer to 10 for SEL than it was for EPNL, and the correlation coefficient at a K value of 10 for SEL was indeed greater than for EPNL.

The correlation coefficient for L_{np} was significantly less than for its parent measure L_{eq}. The addition of the term to account for standard deviation in noise level degraded the performance of the measure. A very similar result was found in the laboratory study of reference 5.

Effects of Subject Experience

As pointed out earlier, in one recent laboratory study (ref. 5) a unique effect was found which was concerned with subject experience and the relative importance of the numbers of events on annoyance. In that study, it was suggested that the effect could have been the result of the subjects' learning experiences or a consequence of the particular experimental design. The present study was designed so that subject experiences or learning effects could be investigated in more detail.

Effects of laboratory experience.- To determine the influence of laboratory experience on the subjects' annoyance judgments, each subject group was exposed to five different number-level conditions. When considered across all subject groups, each of the 25 number-level conditions occurred an equal number of times in each of the 5 order positions. As a consequence, regression analyses for effects of level and number could be performed for each of the five order positions.

The analysis of variance for the laboratory annoyance question (table III) indicated no significant effect of order, although small but significant effects of interaction between order and level and between order and number were found. These results were further examined by performing separate linear regression analyses of level (L_A) and number (log N) on the normalized annoyance responses for each order position. The results of these analyses are given in table X. The means of the normalized responses indicated no systematic effects of order. Thus, subjects' mean annoyance judgments were not affected by their amount of laboratory experience. The regression coefficient for number effect indicated

a generally consistent increase. This indicates that subjects' sensitivities to changes in exposure increased with laboratory experience.

Although the effect of number of flyovers increased with increased subject experiences, an effect of number was found even for the first exposure or order position. This was different from the finding of reference 5 in which no effect of number was found for first exposure conditions. One possible explanation for this difference in results could be a difference in previous aircraft noise exposure in the subjects' home environments. The subjects in the present study in general were probably exposed to aircraft noise more frequently than those in reference 5 even though neither set of subjects had participated in previous laboratory annoyance tests. The possible effects of home experience with aircraft noise exposure are examined in the following section.

Effects of home experience.- The estimated exposure of the test subjects to aircraft noise in their homes was categorized into four NEF exposure ranges as indicated in table XI. These exposures were obtained from noise contours for the Langley Air Force Base area and for the Patrick Henry International Airport area. Subjects were categorized into the exposure groups depending on listed home address. The mean and standard deviation of laboratory annoyance response and linear regression results for level and number as related to home aircraft noise exposure are presented in table XI. A consistent decrease in response was found for increased home exposure. Based on t-tests, the decrease was significant between the extreme categories. However, no consistent trends for differences with exposure were found for the regression coefficients for number or level effects. Thus based on the somewhat limited range of exposure, it appeared that previous exposure history had little or no effect on differential sensitivity to changes in noise level or number of flyover events. However, subjects from areas of more intense exposure were generally less annoyed by the same laboratory exposure than subjects from areas of less intense exposure. As a consequence, very little insight into the difference in the number effect for first exposures between reference 5 and the present study is provided by knowledge of the subjects' home noise exposure.

Cumulative Annoyance to Longer Exposures

At the conclusion of the five noise sessions, the subjects were asked individually a final question about the annoyance to all of the noise they had heard. The primary objective of this question was to furnish some information on how subjects integrated their feelings of annoyance over longer periods and in particular to determine whether the events which occurred toward the end of the period were weighed more heavily than those which occurred earlier in the period.

The individual subject responses to this overall annoyance question were compared with the responses to the separate noise sessions using a forward stepwise regression analysis. A summary of this analysis is given in table XII. The separate session annoyance variable first entered was for the second session. The F-values to enter the responses of each of the other sessions were significant at the 0.01 level. The regression coefficients for all variables were very similar, as were the simple correlations of each variable with the

overall response. None of the simple correlations were significantly different from the others.

Based on this analysis, it appeared that over periods of 2 to 3 hours, events occurring near the end of the period were no more influential in determining annoyance response to the whole period than were events occurring earlier in the period.

Several additional regression analyses were conducted. In one analysis the dependent variable was the overall response and the independent variable was the mean of the five session responses for each subject. This analysis resulted in a correlation coefficient of 0.634 as compared with 0.635 for the stepwise regression of table XII. In another analysis, the maximum of the five session responses was used as the independent variable. This resulted in a correlation coefficient of 0.539, which was significantly less ($p \leq 0.01$) than for the mean of the five responses. The result of these two analyses indicated that the subject judgments over the longer periods were more likely based on an arithmetic mean of their annoyance at different times during the period than on an energy mean.

Comparison with Community Surveys

One method which has found some favor in recent years for unifying the reporting of annoyance in community surveys and laboratory studies is to describe subjects' responses in terms of percentage of people highly annoyed (refs. 5 and 11). The description "highly annoyed" has been interpreted in reference 5 as being the point at which the respondent would find the noise unacceptable enough to consider doing something about the noise, such as moving or complaining to authorities. The percentage of subjects in the present study who reported they would be highly annoyed during one or more of the periods is presented in table XIII. The results for the separate day, evening, and night periods are compared in figure 6 as a function of estimated outdoor noise level in L_{eq}. The three lines represent trends for linear regressions on L_{eq} of unit normal deviates (Z-scores) which were associated with the values of percentage highly annoyed as areas under the normal probability distribution curve. Although the data have considerable scatter, more of the subjects thought they would be highly annoyed by the noises if they occurred at night rather than during the evening or day. Similarly, more subjects thought they would be highly annoyed during the evening than during the day.

Some cumulative exposure noise metrics incorporate penalties expressed as a number of decibels to be added to the level of events occurring during night and evening to account for possible increased annoyance relative to events occurring during the day. Based on the data of figure 6, an appropriate value for evening penalties would be approximately 5 dB, and an appropriate value for night penalties would range from 8 to 15 dB, depending somewhat on noise level.

The results of the pooled scores for the three time periods are compared in figure 7 with the survey results of reference 10. The survey results represented by the solid curve are based on the third-order polynomial suggested in

Over the range of realistic noise levels (L_{eq} or L_{dn} values of 50 to 80 dB), the curve of reference 11 does not deviate appreciably (based on normal probability scale) from the linear regression line of the pooled data of the present study. No particular trends in deviation from the regression line are apparent in the data of the present study for different numbers of flyovers per half-hour noise session.

CONCLUSIONS

Subjects in a simulated living room environment judged the annoyance of half-hour sessions of airplane noise which contained different noise levels and numbers of flyovers. Subject experience and normal home noise exposure were also considered in some analyses. The subjects also projected how they would feel about the noises if heard in their own homes and whether they would be highly annoyed during day, evening, and night periods. Findings of the study of importance to the assessment of community-noise annoyance are as follows:

1. A general increase in annoyance was found for both increases in noise level and increases in the number of flyovers in a session. The "dB(A) peak concept" was therefore not substantiated. The increase in annoyance with number of flyovers was somewhat less at high noise levels and high numbers of flyovers than at low noise levels or low numbers of flyovers.

2. The optimum correction to noise levels to account for the number of flyovers was found to depend on the noise level metric and was equivalent to a 4- to 6-dB change in level per doubling or halving of the number of flyovers for the metrics examined. Thus, the effect of number was somewhat greater than the 3 dB per doubling implied in energy-based metrics.

3. Although the subjects' mean annoyance judgments were not affected by their amount of laboratory experience, the regression coefficients for both level and number increased with increased laboratory experience. Thus the subjects' sensitivity to change in exposure increased with experience.

4. The subjects' mean laboratory annoyance judgments were found to decrease with increased home aircraft exposure. However, the regression coefficients of both level and number of flyovers were not found to be related to their home exposure.

5. Based on the results of the responses of the subjects to the questions of annoyance projected to their home environments, appropriate time-of-day penalties were found to be 5 dB for evening events and 8 to 15 dB, depending on exposure, for night events relative to day events.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
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APPENDIX A

INSTRUCTION AND SCORING SHEETS

Instructions

The experiment in which you are participating today is to help us understand the reactions of people to various aircraft noise environments. There will be five sessions of aircraft noise, each lasting about 30 minutes. At the end of each session, we would like you to make several different judgments on the noises you just heard.

You will be given a scoring sheet for each session which has four scales numbered "0 to 10," the end points of which are labeled "Not Annoying At All" and "Extremely Annoying." An example of these scoring sheets is on the final page of this instruction set. Your judgment in all cases should be indicated by circling one of the numbers on the scale. If you judge the noise to be very annoying then you should circle a number closer to the "Extremely Annoying" end of the scale. Similarly if you judge the noise to be only slightly annoying you should circle a number closer to the "Not Annoying At All" end of the scale.

For the first question and scale, we would like to know how annoying you found the noise of the session. That is, your judgment should reflect your feelings of annoyance in our laboratory situation.

For the next question and the last three scales, we would like you to imagine how you would feel about the noise if you heard it in your home. The first of these last scales is for your judgment of how annoying the noise would be if you heard it during the day, say between 7 a.m. and 7 p.m. The second scale is for your judgment of how annoying the noise would be in the evening, say between 7 p.m. and 11 p.m. The third scale is for your judgment of how annoying the noise would be at night, say between 11 p.m. and 7 a.m. In making these last three judgments, we would like for you to consider all your home activities during each of the time periods and how you would feel about living with the noise day after day.

Also on each scoring sheet are two additional questions concerning your annoyance to the noises you just heard. On these questions you are to circle either the yes or no response if you were or would be highly annoyed by the noise. That is, whether or not you would consider doing something about the noise, such as moving or complaining to authorities. The first of these questions is for your feelings in our laboratory situation. The second is for your feelings if you heard the noise in your home during the day, evening or night periods.

There are no correct answers, we just want a measure of your own personal reaction to the noise in each session. For this reason, we request that you do not talk during the tests nor express any emotion which might influence the

response of the other people in the room. During each of the sessions, we would like you to relax and read or do any needlework you may have brought with you.

Thank you for helping us with this investigation.

APPENDIX A

Scoring Sheet

Subject No.___________________ Group___________________

Seat__________________________ Session__________________

Code__________________________ Date ____________________

1. How annoying was the noise in the session?

Not Annoying At All 0 1 2 3 4 5 6 7 8 9 10 Extremely Annoying

2. How annoying would the noise be in your home?

(a) During the <u>day</u>

Not Annoying At All 0 1 2 3 4 5 6 7 8 9 10 Extremely Annoying

(b) During the <u>evening</u>

Not Annoying At All 0 1 2 3 4 5 6 7 8 9 10 Extremely Annoying

(c) During the <u>night</u>

Not Annoying At All 0 1 2 3 4 5 6 7 8 9 10 Extremely Annoying

3. Were you highly annoyed by the noise in the session?

Yes No

4. Would you be highly annoyed by the noise in your home?

(a) During the <u>day</u>

Yes No

(b) During the <u>evening</u>

Yes No

(c) During the <u>night</u>

Yes No

APPENDIX B

ANALYSIS OF VARIANCE SUMMARY TABLES

TABLE B1.- ANALYSIS OF VARIANCE SUMMARY TABLE FOR LABORATORY ANNOYANCE QUESTION

Source	Degrees of freedom	Sum of squares	Mean square	F-ratio
Between replications (R) . . .	1	12.10	12.10	
Within replications	1224			
Between subjects	248	3023.81		
Between groups	48	953.89		
(OA)	8	150.75	18.84	
(OB)	8	105.23	13.15	
(AB)	8	88.11	11.01	
(OAB)	24	609.79	50.82	
Subjects within groups . .	200	2069.92	10.35	
Within subjects	976			
(OA)	24	143.49	5.98	2.81*
(OB)	24	113.84	4.74	2.23*
(AB)	24	176.35	7.35	3.45*
(OAB)	104	371.70	3.57	1.68*
Error	800	1702.88	2.13	
Between orders (O)	4	11.87	2.97	1.39^{ns}
(RO)	4	31.33	7.83	
Between levels (A)	4	1958.92	489.73	230.07*
(RA)	4	28.64	7.16	
Between numbers (B)	4	717.04	179.26	84.21*
(RB)	4	13.94	3.49	
Total	1249	8305.91		

*Significant at 0.01 level.
^{ns}Not significant.

TABLE B2.- ANALYSIS OF VARIANCE SUMMARY TABLE FOR HOME-PROJECTED DAY QUESTION

Source	Degrees of freedom	Sum of squares	Mean square	F-ratio
Between replications (R) . . .	1	11.52	11.52	
Within replications	1224			
Between subjects	248	3110.36		
Between groups	48	906.28		
(OA)	8	122.10	15.26	
(OB)	8	143.92	17.99	
(AB)	8	91.43	11.43	
(OAB)	24	548.83	45.74	
Subjects within groups . .	200	2204.08	11.02	
Within subjects	976			
(OA)	24	112.38	4.68	1.90*
(OB)	24	137.77	5.74	2.33*
(AB)	24	154.36	6.43	2.61*
(OAB)	104	357.66	3.44	1.40*
Error	800	1968.72	2.46	
Between orders (O)	4	6.84	1.71	0.70ns
(RO)	4	30.18	7.55	
Between levels (A)	4	1935.08	483.77	196.58*
(RA)	4	28.65	7.16	
Between numbers (B)	4	718.33	179.58	72.97*
(RB)	4	10.42	2.61	
Total	1249	8582.27		

*Significant at 0.01 level.
nsNot significant.

TABLE B3.- ANALYSIS OF VARIANCE SUMMARY TABLE FOR HOME-PROJECTED EVENING QUESTION

Source	Degrees of freedom	Sum of squares	Mean square	F-ratio
Between replications (R) . . .	1	10.58	10.58	
Within replications	1224			
Between subjects	248	3613.39		
Between groups	48	1114.75		
(OA)	8	78.81	9.86	
(OB)	8	206.64	25.83	
(AB)	8	152.48	19.06	
(OAB)	24	676.82	56.40	
Subjects within groups . .	200	2498.64	12.49	
Within subjects	976			
(OA)	24	131.83	5.49	1.87*
(OB)	24	133.14	5.55	1.88*
(AB)	24	165.88	6.91	2.35*
(OAB)	104	434.85	4.18	1.42*
Error	800	2354.96	2.94	
Between orders (O)	4	65.08	16.27	5.53*
(RO)	4	35.06	8.77	
Between levels (A)	4	2211.81	552.95	187.84*
(RA)	4	28.07	7.02	
Between numbers (B)	4	953.23	238.31	80.95*
(RB)	4	7.68	1.92	
Total	1249	10 145.57		

*Significant at 0.01 level.

TABLE B4.- ANALYSIS OF VARIANCE SUMMARY TABLE PROJECTED NIGHT QUESTION

Source	Degrees of freedom	Sum of squares	Mean square	F-ratio
Between replications (R) . . .	1	1.55	1.55	
Within replications	1224			
Between subjects	248	5030.16		
Between groups	48	1784.08		
(OA)	8	231.60	28.95	
(OB)	8	395.82	49.48	
(AB)	8	198.86	24.86	
(OAB)	24	957.79	79.82	
Subjects within groups . .	200	3246.08	16.23	
Within subjects	976			
(OA)	24	151.57	6.32	1.82*
(OB)	24	162.00	6.75	1.95*
(AB)	24	194.58	8.11	2.34*
(OAB)	104	576.51	5.54	1.60*
Error	800	2774.72	3.47	
Between orders (O)	4	130.36	32.59	9.40*
(RO)	4	44.67	11.17	
Between levels (A)	4	2408.23	602.06	173.58*
(RA)	4	23.90	5.97	
Between numbers (B)	4	1127.99	282.00	81.30*
(RB)	4	2.28	0.57	
Total	1249	12 682.51		

*Significant at 0.01 level.

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TABLE I.- NOISE LEVELS PRESENTED TO SUBJECTS,

EXPRESSED IN FOUR DIFFERENT METRICS

Level designation	L_A	SEL	TCPNL	EPNL
Measured indoor noise levels, dB				
1	55.6	66.4	67.6	65.4
2	62.4	71.8	73.7	72.6
3	68.8	77.1	80.2	79.1
4	72.5	81.6	85.3	83.5
5	79.6	86.8	94.8	90.6
Estimated outdoor noise levels, dB				
1	75.2	85.5	78.2	78.4
2	82.2	91.6	85.2	85.4
3	88.5	96.8	92.6	92.2
4	91.9	101.0	96.5	95.3
5	99.6	106.8	108.4	103.4

TABLE II.- PRESENTATION ORDER OF EXPERIMENTAL CONDITIONS

Subject group	Order				
	1	2	3	4	5
1	1A	2B	5E	3C	4D
2	2E	3A	1D	4B	5C
3	3D	4E	2C	5A	1B
4	4C	5D	3B	1E	2A
5	5B	1C	4A	2D	3E
6	1E	2A	5D	3B	4C
7	2D	3E	1C	4A	5B
8	3C	4D	2B	5E	1A
9	4B	5C	3A	1D	2E
10	5A	1B	4E	2C	3D
11	1D	2E	5C	3A	4B
12	2C	3D	1B	4E	5A
13	3B	4C	2A	5D	1E
14	4A	5B	3E	1C	2D
15	5E	1A	4D	2B	3C
16	1C	2D	5B	3E	4A
17	2B	3C	1A	4D	5E
18	3A	4B	2E	5C	1D
19	4E	5A	3D	1B	2C
20	5D	1E	4C	2A	3B
21	1B	2C	5A	3D	4E
22	2A	3B	1E	4C	5D
23	3E	4A	2D	5B	1C
24	4D	5E	3C	1A	2B
25	5C	1D	4B	2E	3A

Note: 1, 2, 3, 4, and 5 indicate A-weighted peak noise levels of 55.6, 62.4, 68.8, 72.5, and 79.6 dB, respectively.

A, B, C, D, and E indicate 1, 3, 5, 9, and 17 flyovers per session, respectively.

TABLE III.- ABBREVIATED RESULTS FROM ANALYSIS OF VARIANCE

FOR LABORATORY ANNOYANCE QUESTION

Effect	Degrees of freedom	F-ratio
Order	4	1.39[ns]
Level	4	230.07*
Number	4	84.21*
Order × level	24	2.81*
Order × number	24	2.23*
Level × number	24	3.45*
Order × level × number . .	104	1.68*
Error	800	

*Significant at 0.01 level.
[ns]Not significant.

TABLE IV.- ABBREVIATED RESULTS FROM ANALYSIS OF VARIANCE

FOR HOME-PROJECTED DAY QUESTION

Effect	Degrees of freedom	F-ratio
Order	4	0.70[ns]
Level	4	196.58*
Number	4	72.97*
Order × level	24	1.90*
Order × number	24	2.33*
Level × number	24	2.61*
Order × level × number . .	104	1.40*
Error	800	

*Significant at 0.01 level.
[ns]Not significant.

TABLE V.- ABBREVIATED RESULTS FROM ANALYSIS OF VARIANCE

FOR HOME-PROJECTED EVENING QUESTION

Effect	Degrees of freedom	F-ratio
Order	4	5.53*
Level	4	187.84*
Number	4	80.95*
Order × level	24	1.87*
Order × number	24	1.88*
Level × number	24	2.35*
Order × level × number . .	104	1.42*
Error	800	

*Significant at 0.01 level.

TABLE VI.- ABBREVIATED RESULTS FROM ANALYSIS OF VARIANCE

FOR HOME-PROJECTED NIGHT QUESTION

Effect	Degrees of freedom	F-ratio
Order	4	9.40*
Level	4	193.59*
Number	4	81.30*
Order × level	24	1.82*
Order × number	24	1.95*
Level × number	24	2.34*
Order × level × number . .	104	1.60*
Error	800	

*Significant at 0.01 level.

TABLE VII.- MULTIPLE REGRESSION RESULTS AND OPTIMUM NUMBER CORRECTION FOR DIFFERENT NOISE MEASURES

Individual flyover noise level measure	Noise level effect		Number effect		Relative number effect		Optimum correction, dB per doubling of number of flyovers
	β_1	σ_1	β_2	σ_2	K (β_2/β_1)	95% confidence limits	
L_A	0.0803	0.00679	1.291	0.133	16.1	±4.2	4.8 ± 1.3
SEL	.0923	.00791	1.291	.135	14.0	±3.7	4.2 ± 1.1
TCPNL	.0658	.00471	1.291	.115	19.6	±4.4	5.8 ± 1.3
EPNL	.0779	.00643	1.291	.131	16.6	±4.3	5.0 ± 1.3

TABLE VIII.- CORRELATION MATRIX AND t-TESTS FOR DIFFERENCES BETWEEN

ANNOYANCE PREDICTABILITY OF SINGLE-EVENT NOISE MEASURES

		Calculated t-value for difference between noise measures			
	Noise measure	TCPNL	L_A	EPNL	SEL
Correlation coefficient	TCPNL		0.936^{ns}	1.048^{ns}	1.070^{ns}
	L_A	0.995		0.704^{ns}	0.221^{ns}
	EPNL	0.995	1.000		0.047^{ns}
	SEL	0.995	0.998	0.999	
	Annoyance	0.753	0.740	0.738	0.738

^{ns}Not significant.

TABLE IX.- CORRELATION MATRIX AND t-TESTS FOR DIFFERENCES BETWEEN

ANNOYANCE PREDICTABILITY OF CUMULATIVE NOISE MEASURES

		Calculated t-value for difference between noise measures			
	Noise measure	NNI	L_{eq}	NEF	L_{np}
Correlation coefficient	NNI		3.628*	4.058*	3.109*
	L_{eq}	0.994		2.223*	1.956*
	NEF	0.986	0.995		1.181^{ns}
	L_{np}	0.903	0.909	0.874	
	Annoyance	0.963	0.943	0.928	0.885

*Significant at 0.05 level.
^{ns}Not significant.

TABLE X.- EFFECTS OF TEST SESSION ORDER ON ANNOYANCE JUDGMENTS

Session order	Mean normalized response	Coefficient of level effect, β_1	Coefficient of number effect, β_2	Ratio of coefficients β_2/β_1
1	-0.685	0.0685	0.769	11.2
2	-.787	.0768	1.276	16.6
3	-.602	.0833	1.362	16.4
4	-.759	.0882	1.490	16.9
5	-.731	.0835	1.777	21.3

TABLE XI.- EFFECTS OF HOME EXPOSURE TO AIRCRAFT NOISE ON LABORATORY ANNOYANCE

Home exposure to aircraft noise NEF	Number of judgments	Mean laboratory annoyance	Standard deviation	Coefficient of level effect, β_1	Coefficient of number effect, β_2	Ratio of coefficients, β_2/β_1
<20	710	2.54	2.61	0.144	1.91	13.3
20 to 25	160	2.53	2.62	.146	1.52	10.4
25 to 30	190	2.04	2.50	.146	1.91	13.1
>30	100	1.60	2.18	.120	1.44	12.0

TABLE XII.- SUMMARY TABLE OF STEPWISE REGRESSION OF CUMULATIVE ANNOYANCE AND ANNOYANCE TO SEPARATE SESSIONS

Variable entered, annoyance to session	Coefficient of entering variable	F-ratio to enter	r	R	Change in R^2
2	0.173	48.8*	0.406	0.406	0.165
5	.176	36.3*	.385	.522	.107
1	.205	22.8*	.401	.578	.062
4	.163	14.9*	.360	.610	.038
3	.151	12.6*	.374	.635	.031

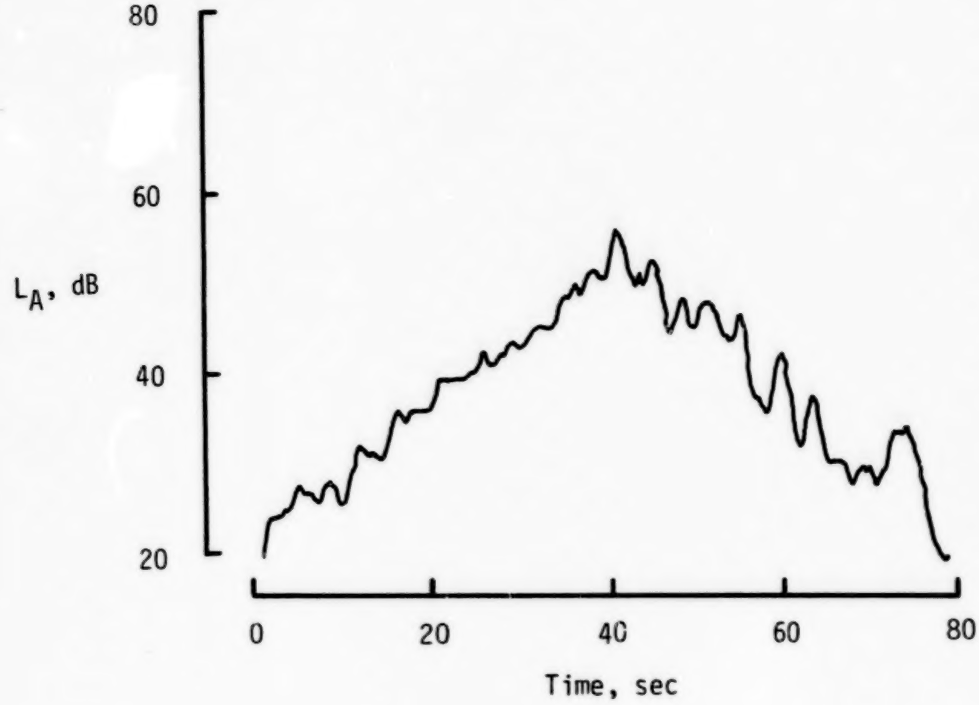
*Significant at 0.01 level $\left[F_{1,\infty}(0.01) = 6.63\right]$.

TABLE XIII.- PERCENTAGE OF SUBJECTS HIGHLY ANNOYED BASED ON DAY, EVENING, AND NIGHT PROJECTIONS

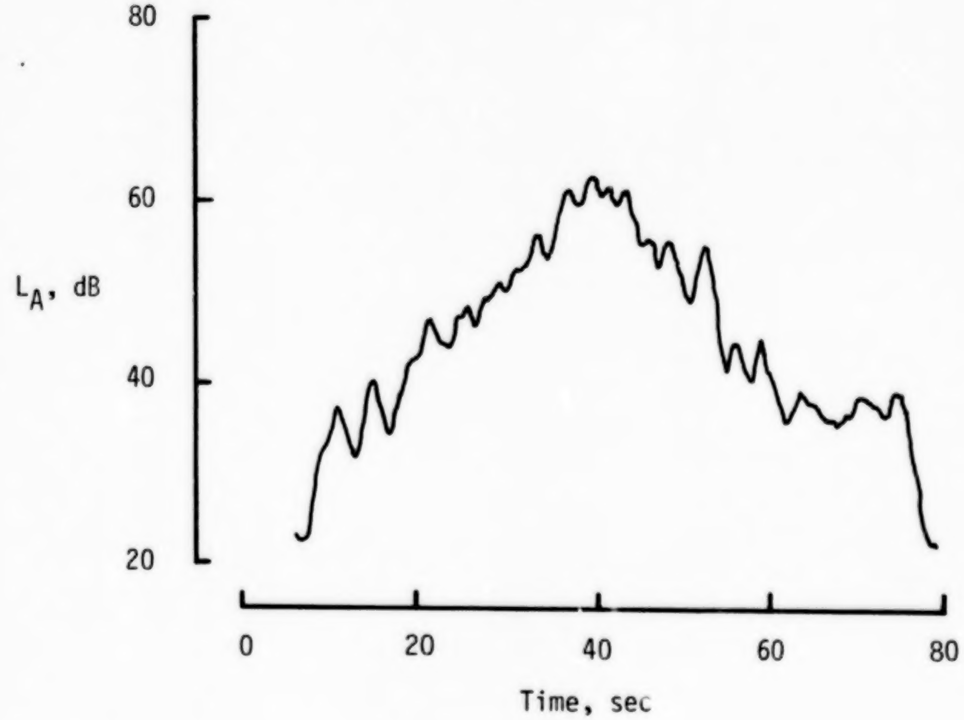
Noise level, L_A, dB	Number of flyovers per session	Percentage of subjects highly annoyed			
		Day	Evening	Night	Pooled
55.6	1	0	2	4	4
55.6	3	0	0	8	8
55.6	5	0	4	14	16
55.6	9	2	2	10	12
55.6	17	8	22	28	36
62.4	1	2	0	8	8
62.4	3	0	4	8	8
62.4	5	2	6	14	14
62.4	9	10	12	22	30
62.4	17	10	14	26	28
68.8	1	2	0	12	14
68.8	3	4	12	22	24
68.8	5	2	6	18	22
68.8	9	4	8	30	34
68.8	17	20	36	44	60
72.5	1	2	10	10	12
72.5	3	10	16	22	28
72.5	5	8	14	34	38
72.5	9	8	18	32	36
72.5	17	22	36	50	60
79.6	1	14	18	26	30
79.6	3	22	50	56	68
79.6	5	42	50	70	78
79.6	9	44	62	68	80
79.6	17	26	48	58	68

L-76-3945

Figure 1.- Photograph of test facility.

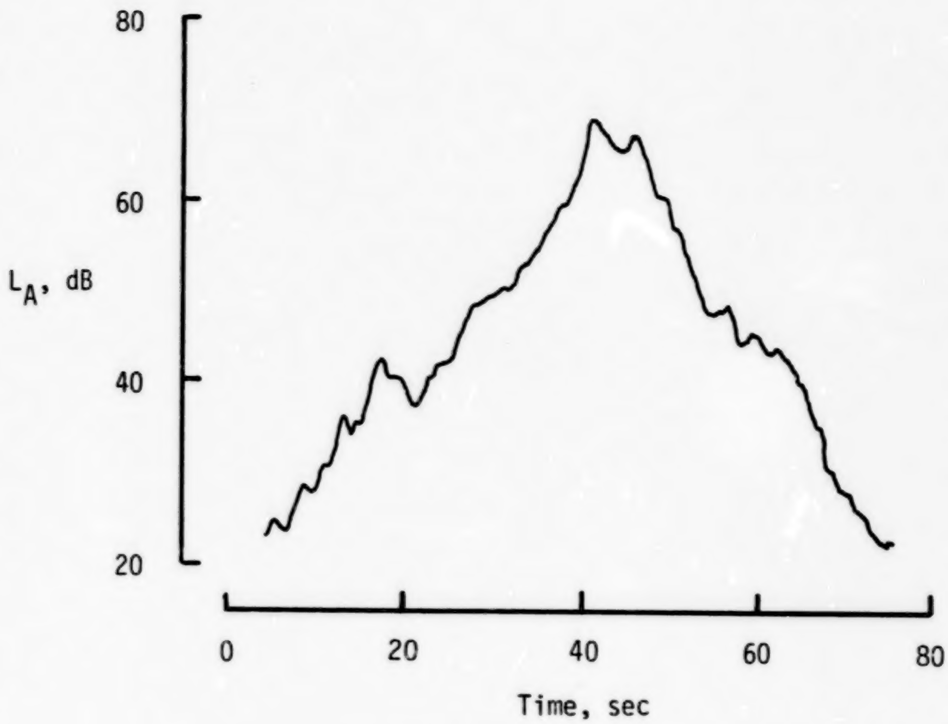


(a) 55.6 dB peak.

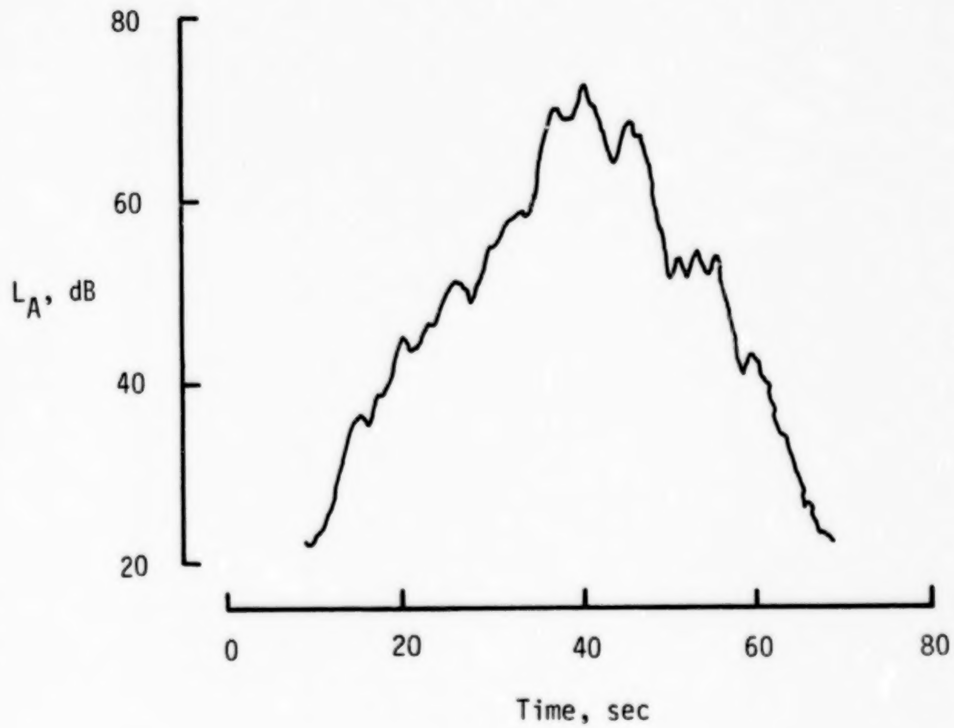


(b) 62.4 dB peak.

Figure 2.- L_A time histories of airplane noise.

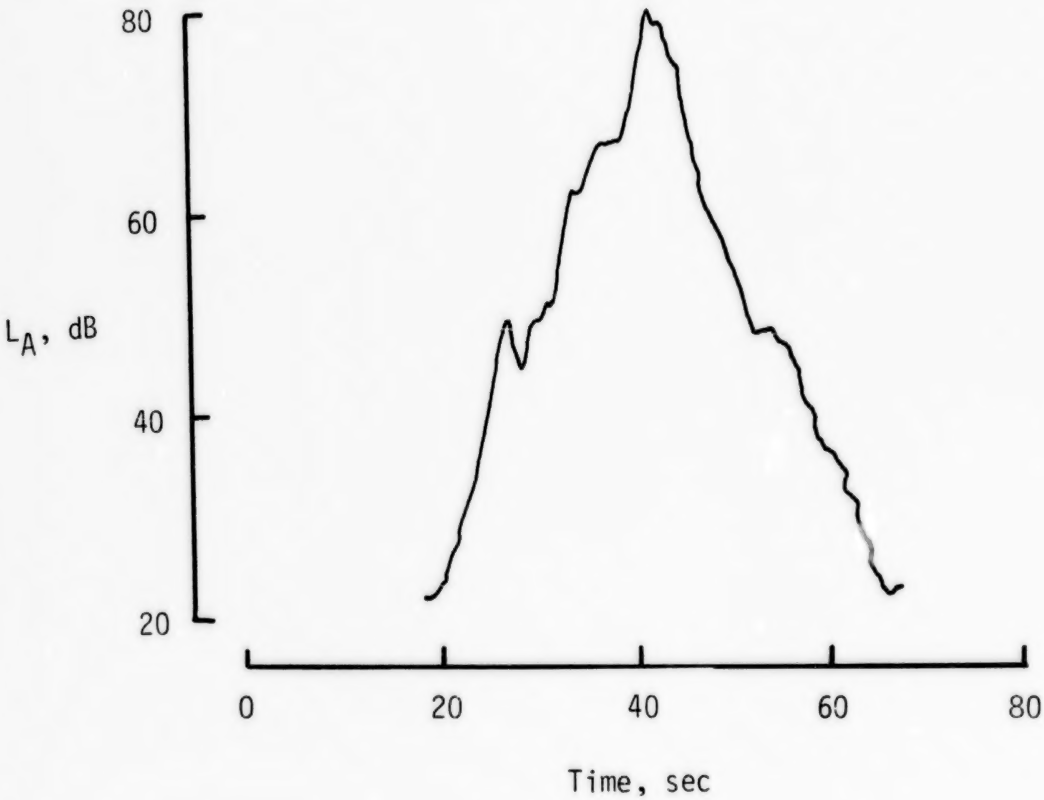


(c) 68.8 dB peak.



(d) 72.5 dB peak.

Figure 2.- Continued.



(e) 79.6 dB peak.

Figure 2.- Concluded.

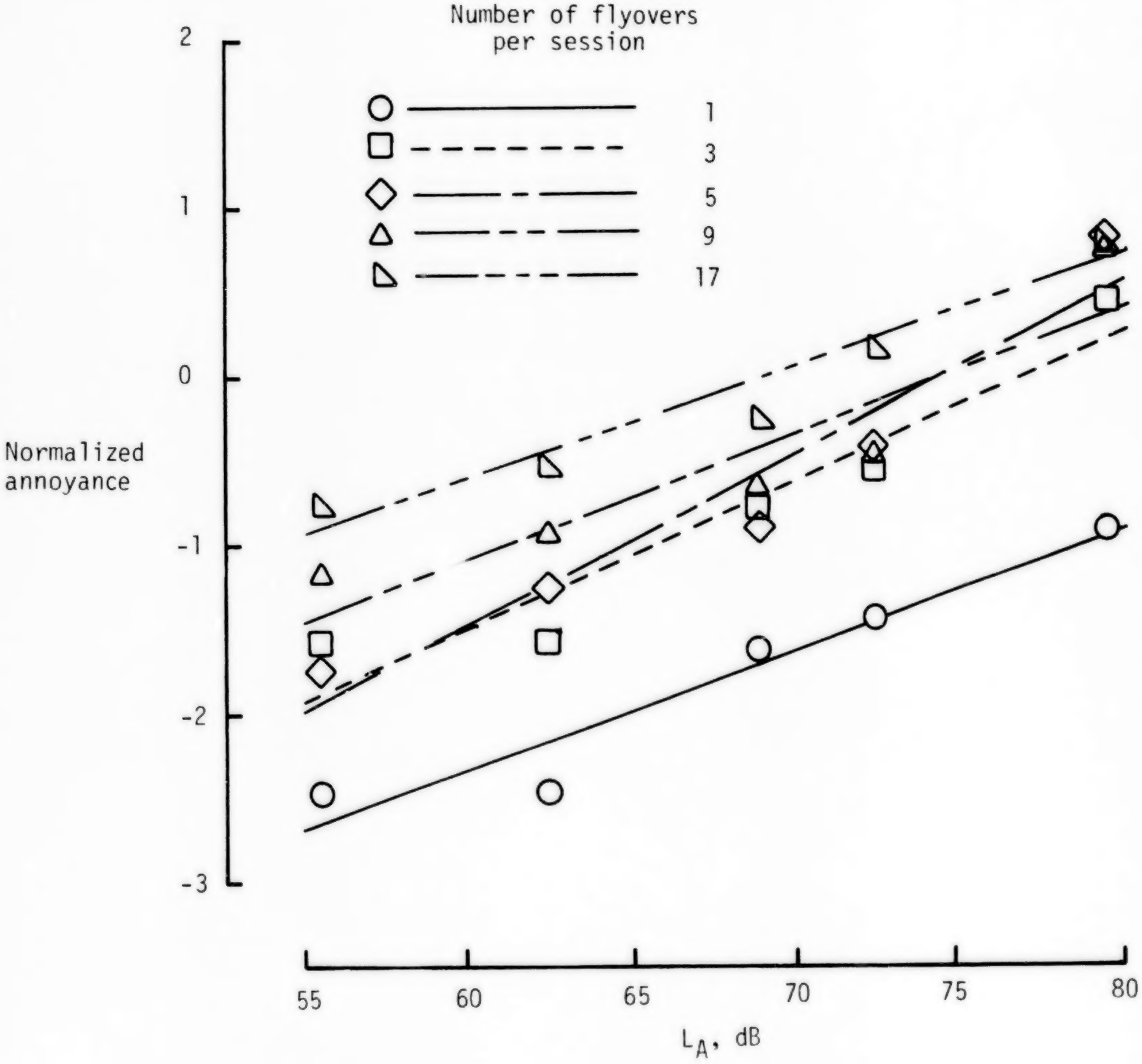


Figure 3.- Effects of noise level on annoyance.

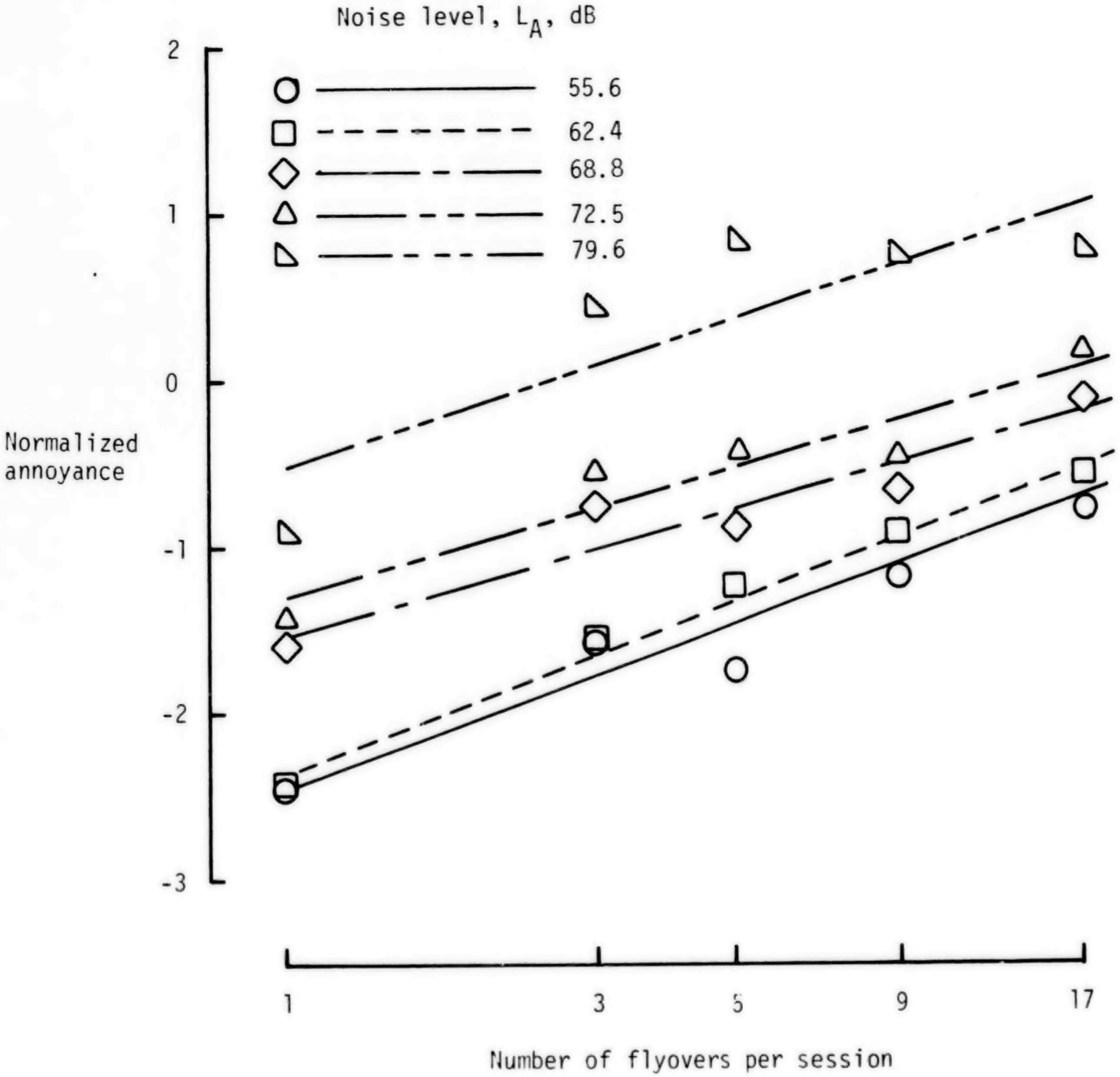


Figure 4.- Effects of number of flyovers on annoyance.

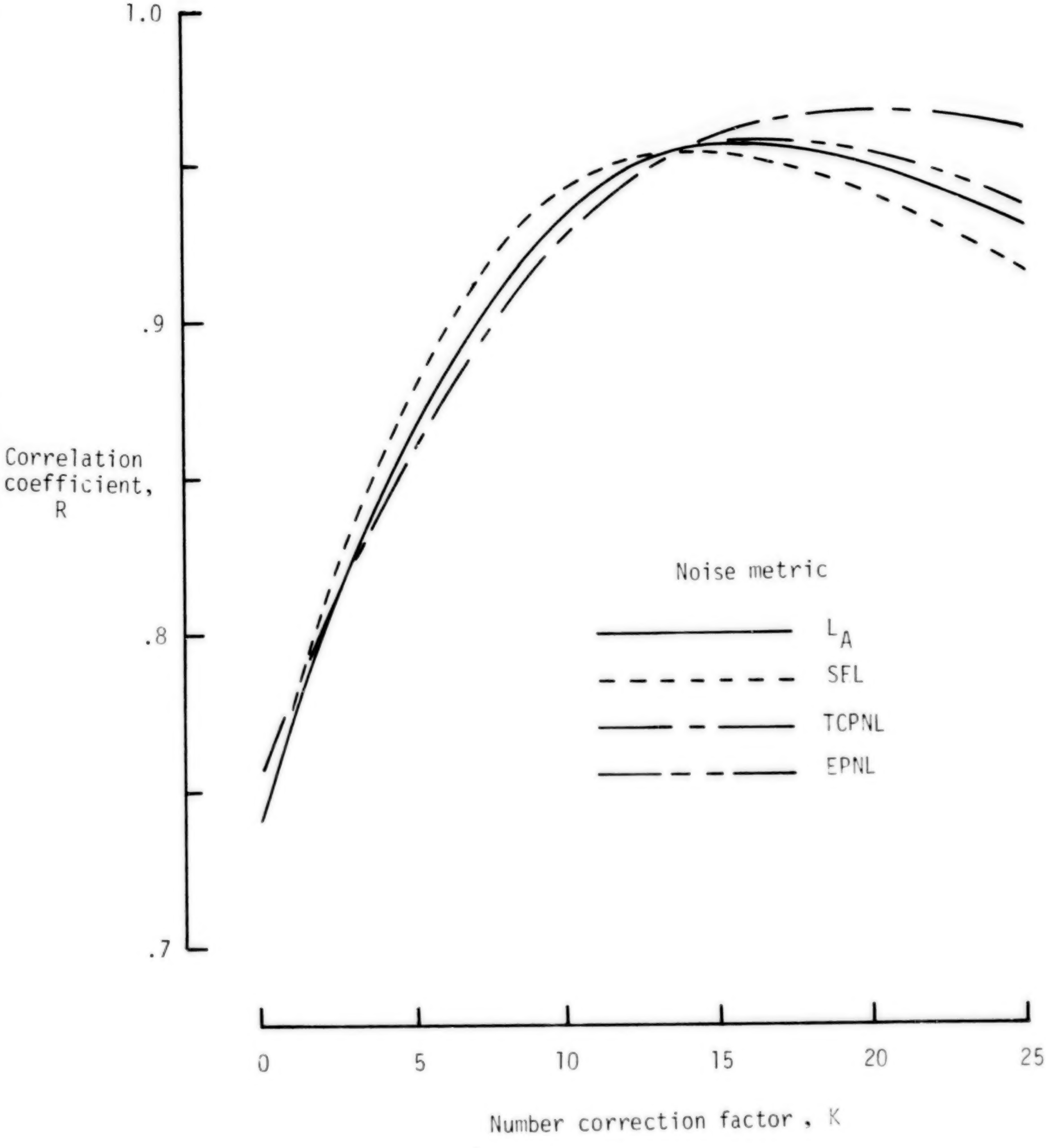


Figure 5.- Effect of number correction factor K on correlation between annoyance and number of flyovers.

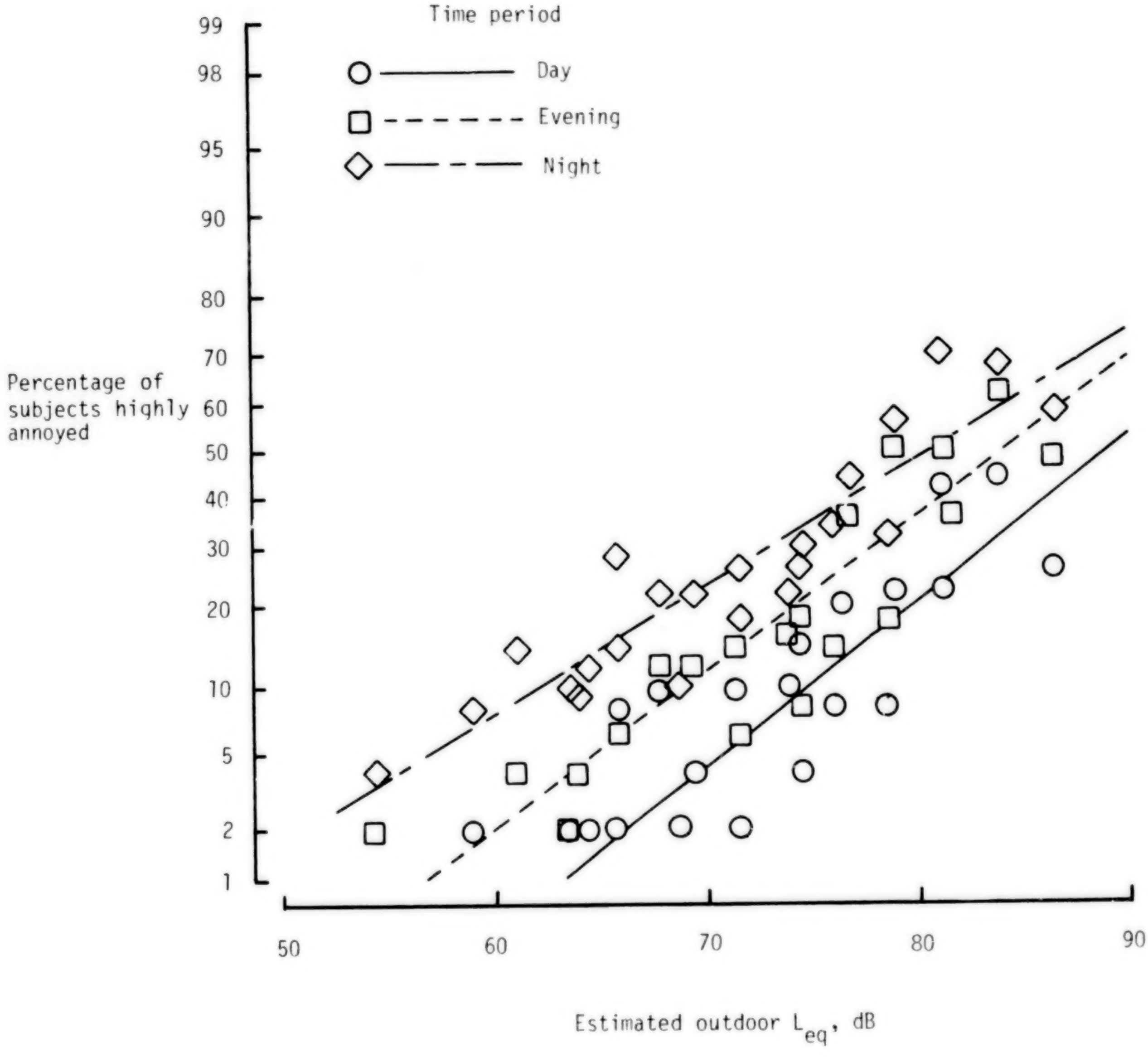


Figure 6.- Comparison of percentage of subjects highly annoyed for day, evening, and night periods.

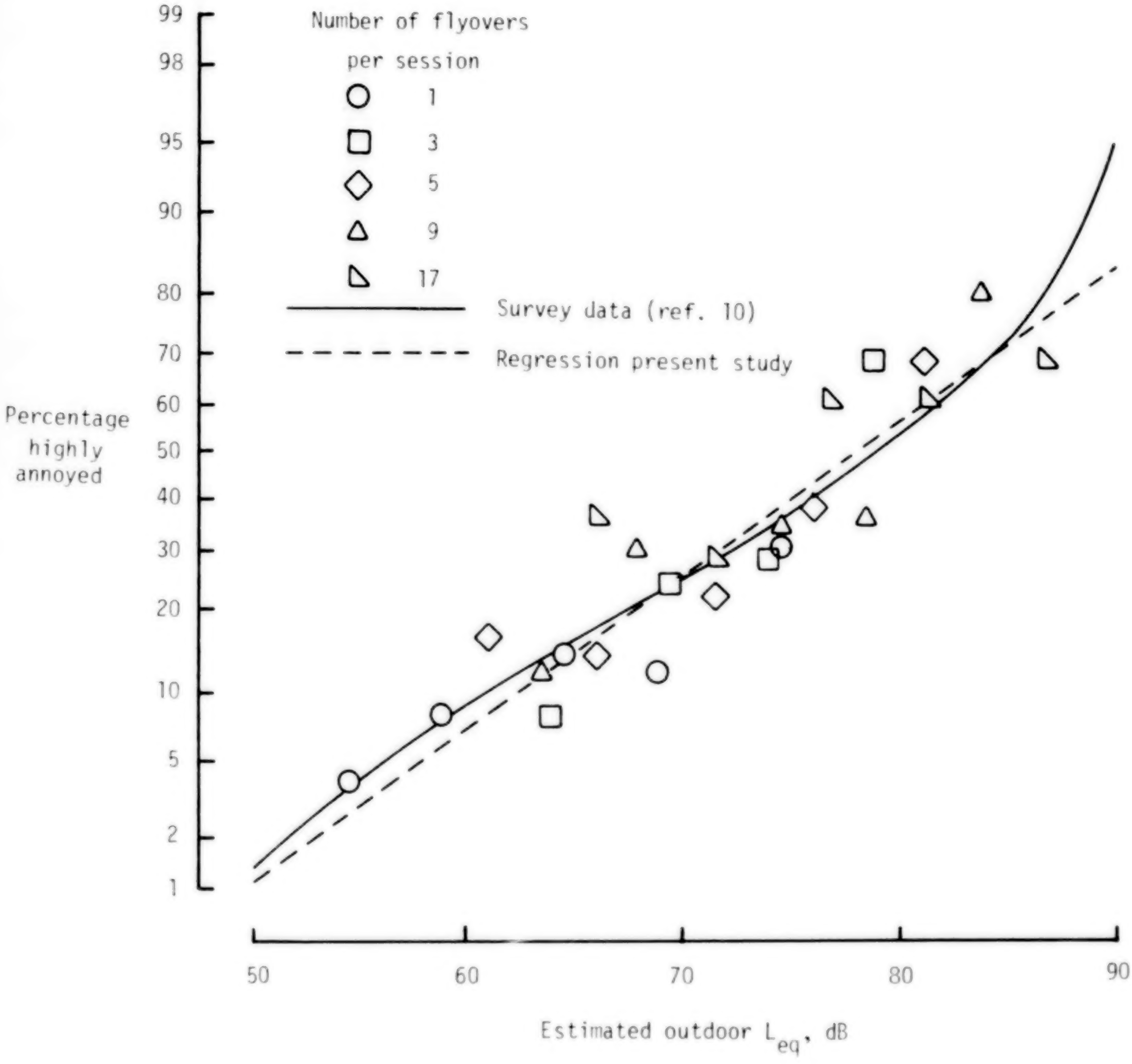


Figure 7.- Comparison of laboratory annoyance with field survey annoyance results.

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15. Supplementary Notes

16. Abstract

A laboratory study was conducted to investigate the annoyance effects of multiple aircraft noise exposure in which 250 subjects judged the annoyance of half-hour periods of airplane noise simulative of typical indoor home exposures. The variables of the aircraft noise exposure were the peak noise level of flyovers (56, 62, 68, 74, and 80 dB(A)), which was constant within each period, and the number of flyovers (1, 3, 5, 9, and 17 per period). Each subject judged 5 of the possible 25 factorial combinations of level and number. Other variables investigated included the experience of the test subjects in making annoyance judgments and their home exposure to airplane noise. The annnoyance judgments increased with both noise level and number of flyovers. The increased annoyance produced by doubling the number of flyovers was found to be the equivalent of a 4- to 6-dB increase in noise level. The sensitivity of the subjects to changes in both noise level and number of flyovers increased with laboratory experience. Although the means of the annoyance judgments made in the laboratory were found to decrease with the subjects' home exposure to aircraft noise, the subjects' sensitivities to changes in both level and number were unaffected by their home exposure.

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